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1 4. LEVEE REMOVAL AND SETBACK

This technique describes the full or partial removal and/or relocation of artificial river and tidal levees for the purpose of habitat restoration. Natural levees are found along the margins of many alluvial stream channels and are formed by the deposition of the coarser part of the sediment load when stream flows exceed channel capacity and the water flows onto the floodplain. Artificial levees, however, are designed to contain high flows within a specified area and have been used ubiquitously throughout the world for flood protection along stream systems and in tidally influenced areas. While initially effective in reducing inundation, levees have numerous drawbacks.

Levees constrain stream flow to a smaller cross-sectional area, and thus velocity and shear stress may be higher for similar discharges. This could cause increased erosion within and along the channel. Vegetation is often removed from the area within the levees, referred to as the “floodway”, in order to decrease roughness, increase velocities, and lower flood stages. Subsequently, this may result in increased erosion of the channel bed, which in turn can cause channel incision and over-steepened streambanks, which can lead to accelerated bank erosion and the introduction of additional sediment into the stream system. In conjunction, the loss of available floodplain reduces areas for sediment storage along the channel. This may cause deposition of sediment within the channel, resulting in aggradation. Sediment produced by erosion of banks in a levee reach and from upstream sediment sources that would naturally be stored in the floodplain or channel is routed downstream causing an increase sediment load to downstream reaches. The increased sediment load to the downstream reach may result in additional aggradation. Aggradation of the channel causes widening and potential avulsion (a complete shift in the channel location). In extreme examples, the channel bottom can aggrade so severely that it becomes perched above the surrounding landscape, in essence flowing along a ridge top.

The use of levees for flood protection generally results in, and even encourages, increased development of floodplain areas because of the perception that the area will not be flooded. Pierce County, Washington has been identified by the National Wildlife Federation as one of the top 300 locations within the United States where there are repeated flood damages of individual properties in excess of $1,000. In fact, repetitive loss properties accounted for only 2% of all National Floodplain Insurance Program (NFIP) properties, but sustained 25% of all NFIP losses, and received 40% of all NFIP payments (NWF, 2002).

Flood damage is typically from levee failure rather than levee overtopping (Mount, 1995). If flood stage exceeds levee height, then overtopping is imminent. The overtopping may cause levee failure by cutting back through the levee at the point where it is overtopped, however, it is much more common to have a failure before overtopping occurs. Because of the hydraulic pressure gradient (the difference in water surface elevations on either side of the levee), seepage occurs through the levee and discharges on the "dry" side. This increases overall pore pressure which reduces shear strength in cohesive materials and, if velocities become great enough, can cause piping, or excavation of material from the inside of the levee, which leads to failure (Mount, 1995). Once a levee is breached, water shoots through the opening at very high velocities, entraining material within its path. The area behind the levee is then inundated and, depending upon the local topography and the levee system, may not be able to naturally drain.

Levee Removal and Setback serves many purposes including: habitat restoration, erosion reduction, water quality improvements, groundwater recharge, wildlife migration corridors, and reduction of flood hazard risks. Levees directly affect floodplain extent and connectivity with the stream channel, which then affects habitat. Undeveloped, natural floodplains provide stream energy dissipation by reducing velocities and providing areas for sediment deposition including organic debris. These low velocity areas provide refuge areas for aquatic species during floods and are excellent habitat for a wide variety of species.

It is preferable to have entire levee removal, but where complete removal is not feasible, the use of setback levees or carefully placed breaches can provide excellent restoration opportunities.

1.1 Introduction

1.1.1 Description of Technique

Levees are defined as artificial embankments, usually of random earth fill, built along the bank of a watercourse or an arm of the sea and designed to protect land from inundation or to confine streamflow to its channel (Gary et al., 1972). Levees are often classified by the type of land use they are protecting. The Natural Resources Conservation Service (NRCS) uses three classes of dikes. Class I dikes are constructed on sites where failure may cause loss of life or serious damage to homes, businesses, or transportation networks. Class II dikes protect areas where failure may result in damage to isolated structures, some infrastructure, and high value crops. Class III dikes are constructed in rural areas and protect lower value agricultural land. Each of these dikes have specific design criteria depending upon the level of protection necessary (NRCS, 1997). There are various types of levees used for flood protection, which include:

1. Parallel levees – built adjacent to a stream channel to confine flows within the active channel. Often used in conjunction with channelization projects, and requires a high structure to minimize flooding because of the minimal cross-sectional area. Riprap bank protection is common with this type of structure.
2. Setback levees – generally parallel to the stream but placed far enough from the active channel to allow overbank flooding and some natural floodplain function. The degree of setback is variable. Structures are generally lower than parallel levees and require less maintenance.

3. Perimeter levees – used primarily to protect individual structures, groups of structures, and wells. Often called "ring dikes" these levees protect small areas from flooding rather than confining flood flows within the stream channel. Levees are generally broad to accomodate equipment and vehicle access and other land uses.
4. Cross-floodplain levees – generally perpendicular to the stream and used to redirect flood flows back into the active channel. They allow floodplain storage of water but no flow parallel to the stream. Roadfill across floodplains can inadvertently function like cross-floodplain levees.
5. Tidal levees – used to protect land specifically from high tide and saline water. This results in the conversion of tidal marshes into other types of habitat. Fresh water can be trapped on the landward side of these levees. Tide gates are often used in conjunction with tidal levees.
6. Deflecting levees – the objective of deflecting levees is for "river training" rather than flood protection. The structure is used to control flow direction during floods. Deflecting levees need not be continuous.

This technique covers levee removal or modifications to levee systems including setback, complete removal, and partial removal including breaching.

1.1.2 Physical and Biological Effects

Physical effects of levee removal and/or setback:

- Change in energy within the channel (usually decrease) and on the floodplain/floodway (usually increase).
- Reduces water surface elevation at the site and upstream during floods.
- Allows for over bank flow and may result in associated increase in groundwater in the floodplain.
- May reduce flood potential to downstream areas by increasing storage of flood water.
- May attenuate sediment transport downstream by providing sediment storage.
- May provide greater channel complexity and/or increased shoreline length.
- Allows increased floodplain flows and thus floodplain channels, diversity and interaction with active channel.
- May stabilize channel reach from chronic erosion or instability due to sediment deposition.
- May create initial and/or chronic instability if the channel has evolved to the hydraulic condition of the presence of the levee.
- May cause changes in channel geometry as newly unconfined channel evolves to new hydrologic situation.
- Restores estuarine functions of temperature, tidal currents, and salinity in the case of tidal levee removal.

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Biological effects

- Allows riparian corridor and riparian function and all associated benefits including shade, wood recruitment supply, organic material supply.
- Restores flood-flow refuge from high velocities.
- May reduce fine sediment in channel and downstream including estuary filling by providing low energy overbank storage areas for fines.
- Restores access of fish and mammals into tributaries, side channels, main channels, estuaries or ocean.
- May allow restoration of saline-dependent plant species and thus increased drainage (tidal levees).
- Allows the restoration of estuarine food production (tidal levees).
- Restores an estuarine transition zone (tidal currents, temperature, salinity) for species migrating through the tidal zone.

1.1.3 Application of Technique

Levee removal or setback applies to all stream systems that have artificial levees in place, but is most beneficial in streams that are not incised and are still capable of accessing their historic floodplains. Focus should be placed on streams where floodplain development is minimal, but may increase in the future. Once floodplains are developed, setback and removal opportunities become extremely expensive and limited. To restore the majority of floodplain functions, the minimum setback distance should be 7 to 10 channel widths (Cowx and Welcomme, 1998).

Areas of specific interest are undeveloped lands, agricultural areas, public lands, and parks. Levee Removal and Setback can be used in conjunction with many other techniques including: channel realignment, land preservation and buy back, riparian and floodplain vegetation, and side channels. The value of Levee Removal and Setback is reinforced by the Restore Channel Cross-Section technique. Floodplain restoration work should often begin prior to removal or setback as long as access is retained for actual construction work. Floodplain restoration work could include restoration of natural floodplain vegetation, flood channels, and active side channels.

1.2 Scale

Levees are structures that may have specific legal constraints due to flood hazards and flood elevations as mapped by the Federal Emergency Management Agency (FEMA). Determining who owns and maintains the levee is critical before an analysis for removal or setback is undertaken. Even if levees are located on private land, the jurisdiction may fall to the US Army Corps of Engineers, local flood control district, or other entity.

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Evaluation of levee removal or setback should occur minimally at the stream reach level. Ideally, an evaluation should encompass an entire watershed, and take into account other potential actions and effects to the reach in question. Areas protected by levees may have significant subsidence due to the disconnection of the contributing water body. Subsidence in conjunction with instream deposition may result in a perched channel condition. Determining the relative elevation of a channel or estuary to the floodplain surface is a critical component for project feasibility and planning. Removal or setback of a levee will likely require an analysis by a registered professional engineer to determine the effects on flood elevations, scour and deposition, and impacts to adjacent lands. If the channel has evolved to an artificial condition in response to the levee confinement, geomorphic and hydrologic analyses should be done.

Removal or setback of small levee systems owned and built by a private landowner, may be easier to accomplish, although impacts to adjacent lands should still be investigated. This becomes more feasible if a levee has breached during a high flow event, and the breach is not repaired.

On a local scale, and generally for individual projects, levee breaches can be used as a low cost alternative to complete levee removal. This allows for inundation of the floodplain, floodwater storage, sediment deposition, and refuge areas for aquatic species. The size and location of breaches should be carefully evaluated to minimize the risk of scour due to flow constriction and channel avulsion in areas where levees are used as river training structures. If open breaches are not acceptable (for example, in areas where an access road is located on the top of the levee), culverts can be placed through the levees to allow some connectivity to the historic floodplain. Natural breaches as a result of flood events provide excellent opportunities to increase breach size or to place culverts.

Reach scale projects are preferable because more floodplain functions are restored and beneficial effects are amplified. It can also potentially reduce the cost per acre because cross-floodplain levees are not required to protect adjacent lands.

1.3 Risk and Uncertainty

Risk and uncertainty for Levee Removal and Setback are relatively low if appropriate analysis and modeling is completed. Risk analysis must include (1) changes to stability, (2) upstream, downstream, and floodplain hydraulic effects, (3) changes to flood hazards, and (4) stream channel response.

Many levees provide bank stabilization due to artificial armoring of the levee bank. Removal of the levee results in removal of the armoring, and hence a potential increase in erosion. Short-term bank protection may be necessary to stabilize bare, erodible banks until native vegetation has become effective. See the ISPG for further guidance.

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A primary hydraulic effect of levee removal is restoration of overbank flows. The designer should be careful to estimate the effects of levee removal in situations where the channel has evolved to some degree to the presence of the levee. An obvious situation is that in which a channel constrained by levees has aggraded. If the levee is removed, the channel capacity is less than it would have been without the levee. In some cases there would be no channel capacity at all. If there are not mature flow channels in the floodplain, this situation can result in years of chaotic channel evolution as it tries to develop a suitable alignment, shape, and slope (refer to Restore Channel Cross-Section).

Hydraulic effects of levee removal or setback include changes in channel and floodplain roughness and a potential change in channel length and slope, which in turn affect velocity and shear stress. Generally, velocity and shear stress will decrease causing a loss in sediment transport capability through the levee removal reach. The reach upstream of a levee removal project may experience increased velocity and shear stress as the backwater of the levee during flood events is eliminated. Sediment deposition on the floodplain should be expected. Hydraulic models are available to help predict these changes. Sediment transport models (HEC-6 and GSTARS) can be used to help address issues with sediment deposition in the restored reach and upstream.

Flood risk can be evaluated using available models, which calculate backwater curves during flood events (HEC-RAS). Flood risk is usually decreased for adjacent areas by the removal or setback of a levee except for the area directly impacted by the activity. Long term flood risk is generally reduced for all areas if the floodplain and channel are returned to a condition in which overbank flows are more predictable and the channel and flood stages are not super-elevated above the surrounding floodplain by being confined by levees.

Stream, estuary, and tidal systems adjust to imposed constraints such as levees. Adjustments may be complete or on-going, but they must be addressed before levee modification is undertaken. The cross-sectional geometry or longitudinal profile of a stream channel may be significantly altered due to a levee on one or both banks. A geomorphic analysis is required to determine potential stream adjustments after the levee is removed. It may be necessary to restore some floodplain functions, such as topography, roughness, and structure, before a levee is removed and it is reconnected to the channel. If possible, compare current channel geometry to pre-levee geometry to assess the extent of channel change. It is also beneficial to determine the rate of change, which will help in predicting the rates of future channel change. Aerial photography is an excellent tool for determining the rates of change for channel planform, but is not helpful for channel geometry changes.

1.4 Data Needs and Assessment

The amount of data collection and assessment required will be dictated by the risk and uncertainty. For most levee removal or setback projects, the following data collection and assessments are required.

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Data Needs:

- Hydrology (high flow frequency, timing, duration) for analysis of flood and sediment effects.
- Topographic survey with cross-sections (including in-channel, levee, floodplain, and surrounding area which will potentially be impacted) for analysis of flood effects and for potential realignment design.
- Section characteristics sufficient for backwater hydraulic modeling including expected in-channel debris, channel variability, and bank and floodplain vegetation type and abundance.
- Land use, property ownership, and infrastructure at risk for analysis of flood risks, to help minimize risks, and to investigate channel alignment alternatives.
- Channel bed and bank materials for sediment and scour analyses.
- Floodplain characteristics (including soils, potential flow paths, vegetation, roughness, infrastructure and natural constraints to channel migration).
- Sediment load and sediment transport characteristics.
- Channel and floodplain cross-sections and floodplain characteristics of a reference channel may be needed if those parameters are not defined at the project site in post-project condition.

Assessment:

- Assess habitat benefit of specific levee removal in terms of specific biological effects that were generally described previously.
- Hydraulic modeling of impacts to river stage during high flow.
- Sediment transport analysis.
- Risk to infrastructure (i.e., roads and bridges) located upstream and downstream
- For levee removal, some form of channel migration hazard study may be needed for establishing potential migration risk (low, medium, high) (this is more likely an issue on medium and large-sized rivers).
- Evaluate upstream and downstream effects of levee removal/setback including flood and sediment storage and rerouting through the floodplain and channel profile changes upstream.
- Evaluate how the stream has responded to the levee over time, and possible permanent or temporary secondary restoration activities needed such as grade control, realignment of channel, and/or revegetation efforts.
- Assess value of various levels of setback. Setback design is often ultimately based on the longevity of sediment storage, and channel migration zone rather than quantifiable hydraulic changes to the channel.

1.5 Methods and Design

The following is a sample design process, which covers the main components required for a levee setback or removal project.

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Design process:

1. Define objectives.
2. Develop topographic maps and hydraulic model of existing condition.
3. Model various scenarios of removal, setback, and breaching including setback distances in terms of sediment storage, flood storage, flood stage, and channel migration.
4. Engineering design for setback levee.
5. Engineering design for any accommodation of levee modification such as channel alignment, grade control, floodplain restoration, and protection of setback levee and/or infrastructure.
6. Bank design as necessary to repair disturbance to banks.
7. Design drawings, specifications, and contracting information.

1.6 Project Implementation

1.6.1 Permitting

Various permits will be required at the local, state, and federal levels depending upon the location on the existing levee system. Counties generally require grading permits and also have regulations regarding work in floodplains (check with the appropriate county and/or city for requirements). Any changes to flood elevations will require additional permitting from the state and county. Construction related permits, including sediment control, spill response, reclamation, and a safety plan will also be required.

If the work is in a riparian area, permits may be required from the state and the federal government. For parallel levees, the work may actually impact a water body and may be restricted to the in-water work window as designated by the state for protection of aquatic species.

Work with the US Fish and Wildlife Service and the National Marine Fisheries Service to determine if there are threatened/endangered species on the property or in the area. Incidental take permits may be required.

1.6.2 Construction

Construction of new setback levees or deconstruction of existing levees requires large equipment in potentially sensitive habitats. Removal of mature riparian vegetation may be necessary to open up the floodplain. Consider saving islands of vegetation to serve as a natural seed bank and to provide at least remnant habitat while the recovers from construction disturbance. Floodplain wetlands may also be impacted by construction activities. A detailed construction plan with specified entry and exit points and travel corridors will help to minimize impacts to vegetatio and soils. Sensitive vegetation areas should be isolated with flagging so that it is clear that equipment should not enter the area. Trees that will be saved or sacrificed should be clearly marked at a height which is easily detectable by an equipment operator. To reduce soil compaction, special equipment for operating on soft ground may be required. If this equipment is not appropriate or available, ripping of the construction access areas to decrease soil compaction may be necessary.

Construction timing should be related to soil moisture conditions, hydrological trends of the contributing water body, and to sensitive plant and animal species.

1.6.2.1 Channel and Floodplain Modifications

It may be necessary to modify the channel upstream and/or downstream from the project site and the floodplain behind the levee before the levee modification is constructed. This may be necessary to reduce the risk of the project as discussed earlier.

An early project task should be an assessment of floodplain characteristics needed to complete the project. For example, if an agricultural field is to be converted to a floodplain, it may be necessary to place debris or other roughness or to plant and manage floodplain vegetation for a period of time so it is ready as functional roughness when the levee removal project is complete.

1.6.2.2 Levee Removal

Levee removal involves establishing entry and exit points, determining haul road locations, removing and/or trimming vegetation, excavating and removing material, ripping the footprint area of the levee if there has been compaction, recontouring of the site, and revegetation. For highly sensitive areas, or areas that have very mature vegetation, consider carefully placed breaches as opposed to full levee removal.

1.6.2.3 Levee Setback

Levee setback requires the same construction components as removal, but also includes rebuilding the setback levee. This requires separating the organics from the excavated levee material if it will be used in the new setback levee. A temporary storage area will also be required until levee construction is complete.

1.6.3 Cost Estimation

Cost estimation for Levee Setback and Removal includes the following items: land acquisition, levee deconstruction, levee construction, bank stabilization, vegetative plantings, construction management, operations and maintenance, and monitoring and tracking.

Land acquisition costs vary widely depending upon current land use and local land prices.

Investigate within the area to determine appropriate land values.

Levee construction/deconstruction and bank stabilization generally require mobilization and demobilization of equipment, pollution control, clearing, recontouring, and excavation, hauling, and disposal of material. For levee setbacks, a temporary storage area is required for the spoil material. Mobilization and demobilization costs will typically be a percentage of the total contract cost (generally 12 to 18%). Pollution control should be a relatively set cost based on the type of equipment on-site and site conditions (up to 20% of excavation cost can be used as an estimate). Excavation, hauling and disposal cost is based on the vlume of material to be moved. Excavation and handling costs will range from one to three dollars per cubic yard ($1 – $3/cy). Hauling cost depends on haul distance, but general estimates can be made based on rental rates for dump trucks. A 10 to 12 cubic yard dump truck rents for approximately $30 – $50/hour. The cost for material disposal will vary greatly depending upon the condition of the material. For clean, uncontaminated material, disposal costs may be very low, or free. Contaminated soil will significantly increase cost. Additional material for levee construction and bank protection may be necessary, which will add to overall project cost.

The cost for reestablishment of vegetation will vary depending upon availability of material and the labor involved in the actual planting. Advanced planning can significantly reduce costs by insuring that specific species are available in the quantities required. Native plant nurseries are becoming more common, and they will often propagate site specific plants for future revegetation efforts.

Construction management is a critical component for project success. Construction management generally costs between five and ten percent of the total project cost. This insures that someone is onsite during the entire construction period.

Operations and maintenance, and monitoring and tracking costs vary greatly and are very project specific. Once a project design is developed, these items can more effectively be cost estimated.

1.6.4 Monitoring and Tracking

Monitoring of floodplains after the removal or setback of levees is rapidly accomplished with aerial photography. Since the reconnection of streams to their floodplains can be very extensive, the aerial photos allow for evaluation of the entire project area. Flow paths, deposition and erosion areas, and changes in vegetation can easily be identified on appropriately scaled aerial photos. For smaller projects, photo points may be sufficient to evaluate general trends.

Specific monitoring items may include installing a simple stream gage to determine when a floodplain becomes activated. This gage can be calibrated to other gages within the basin. Supplemental information may include sediment and debris lines on vegetation. Vegetation type and abundance can be monitored with vegetation transects. Special attention should be given to shifts in vegetative communities and the introduction or eradication of invasive species. Topographic surveys can be used to determine if natural topography is developing on the floodplain (if previously leveled), and the extent of side channel development.

Structural components, such as bank protection or levee integrity, should be evaluated using standard engineering protocols.

1.6.5 Contracting Considerations

- No special considerations.

1.7 Operations and Maintenance

Operations and maintenance applies primarily to levee setback or breaching. Full levee removal, accompanied with appropriate restoration of the floodplain, should require very little or no maintenance beyond the establishment of native vegetation.

An operations and maintenance plan should include specific instructions to insure that the levee or breach area is properly functioning. Requirements to consider include:

- Prompt repair or replacement of damaged components.
- Removal of obstructions from inlet and outlet facilities.
- Periodic check of earthfill elevations.
- Evaluation of the levee surface for cracks in the soil.
- Evaluation of eroding areas, including main channel, side channels, floodplain surface, levee surfaces, and breach areas.
- Evaluation of vegetation condition, distribution, composition, and abundance.

1.8 Examples

Lockwood Creek (tributary to the EF Lewis River) in Clark County, WA. Levee removal with some floodplain excavation to improve fish habitat. Project sponsor is the Clark Conservation District. Implemented in 2000.

1.9 References

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Mount, J.F. 1995. California Rivers and Streams: the conflict between fluvial process and land use. University of California Press: Berkeley.

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NWF (National Wildlife Federation), 2002. Higher Ground: a report on voluntary property buyouts in the nation's floodplains (http://www.nwf.org/floodplain/higherground/index.html).

1.10 Photo and Drawing File Names

List filenames and file locations of any photos and drawing files associated with this technique